The brain, verbs, and the past: Neurolinguistic studies on time reference

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CHAPTER 5

Losing track of time? Incremental time reference processing[1]

Abstract | *Background*: Individuals with agrammatic aphasia (IWAs) have problems with grammatical decoding of tense inflection. However, these difficulties depend on the time frame that the tense refers to. Verb morphology with reference to the past is more difficult than with reference to the non-past, because a link needs to be made to the past event in discourse, as captured in the Past DIscourse LInking Hypothesis (PADILIH; Bastiaanse et al., 2011). With respect to reference to the (non-discourse-linked) future, data so far indicate that IWAs experience less difficulties as compared to past time reference (Bastiaanse et al., 2011), supporting the assumptions of the PADILIH. Previous online studies of time reference in aphasia used methods such as reaction times analysis (e.g., Faroqi-Shah & Dickey, 2009). So far, no such study used eye-tracking, even though this technique can bring additional insights (Burchert, Hanne, & Vasishth, 2013).

Aims: This study investigated (1) whether processing of future and past

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time reference inflection differs between non-brain-damaged individuals (NBDs) and IWAs, and (2) underlying mechanisms of time reference comprehension failure by IWAs.

Methods & Procedures: A visual-world experiment combining sentence-picture matching and eye-tracking was administered to 12 NBDs and 6 IWAs, all native speakers of German. Participants heard German sentences with periphrastic future ('will + V') or periphrastic past ('has + V-d') verb forms while they were presented with corresponding pictures on a computer screen.

Conclusions: NBDs scored at ceiling and significantly higher than the IWAs. IWAs had below-ceiling performance on the future condition, and both participant groups were faster to respond to the past than to the future condition. These differences are attributed to a pre-existing preference to look at a past picture, which has to be overcome. Eye movement patterns suggest that both groups interpret future time reference similarly, while IWAs show a delay relative to NBDs in interpreting past time reference inflection. The results support the PADILIH, because processing reference to the past in discourse syntax requires additional resources and, thus, is problematic and delayed for people with aphasia.

5.1 Introduction

Individuals with agrammatic aphasia (IWAs) typically show tense processing difficulties (Burchert, Swoboda-Moll, & De Bleser, 2005; Friedmann & Grodzinsky, 1997; Wenzlaff & Clahsen, 2004, interalia). Several accounts for the problems with tense inflections exist, but recently, the role of the time frame to which is referred — with either tense inflection or other verb forms — has been highlighted. More specifically, verb forms that refer to the past are impaired in agrammatic aphasia, both in production and comprehension (Abuom & Bastiaanse, 2013; Bastiaanse et al., 2011). Based on an extensive data set of aphasiological production and comprehension, the PAst DIscourse LInking Hypothesis (PADILIH; Bastiaanse et al., 2011; Bastiaanse, 2013) was formulated to describe the pattern of selective impairment of past time reference. The PADILIH claims that reference to the past is discourse-linked, regardless of the anaphoric means employed (i.e., not only through tense as suggested by Zagona, 2003). In order to refer to an event in the past, a link has to be made in discourse. The event is then processed by discourse syntax, which requires more resources and is, therefore, affected in IWAs (Avrutin, 2000, 2006). Events in the here-and-now do not require this link and hence, reference to this time frame is relatively spared. For future time reference, no discourse-linking is needed either, because the event is not in current discourse. Instead, future time reference is derived from present time reference by modal and aspectual morphemes, as suggested by Aronson (1977), Partee (1973), and Zagona (2013).

Importantly, there is a distinction between tense and time reference. In languages such as German and English, an auxiliary in present tense in combination with a participle can be used for past time reference, such as *hat rasiert*: 'has shaved'. For reference to the future, an auxiliary in present tense combined with an infinitive can be used, such as *wird rasieren*: 'will shave'. The problems of IWAs with reference to the past do not only affect past tense, but all verb forms that refer to the past (Bos & Bastiaanse, 2014). In non-brain-damaged speakers (NBDs), electrophysiological and behavioral responses to time reference violations demonstrate differences between present and past tense processing (Dragoy, Stowe, Bos, & Bastiaanse, 2012). In a follow-up study, Bos, Dragoy, Stowe, & Bastiaanse (2013) showed that these differences are, in line with the PADILIH, not related to tense, but to the time reference of the entire verb form.

Recently it has been shown that eye-tracking studies applying the visual-world paradigm (Allopenna, Magnuson, & Tanenhaus, 1998; Cooper, 1974; for a review of visual world studies see Huettig, Rommers, & Meyer, 2011) can provide insights into language processing in non-brain-damaged speakers, as well as in the online and behavioral performance of aphasic individuals (Dickey, Choy, & Thompson, 2007; Dickey & Thompson, 2009; Hanne, Sekerina, Vasishth, Burchert, & De Bleser, 2011; Meyer, Mack, & Thompson, 2012; Mack, Ji, & Thompson, 2013; Thompson & Choy, 2009; for a review on aphasiological visual-world studies see Burchert, Hanne, & Vasishth, 2013). This technique can clarify what occurs when time reference is interpreted incorrectly in agrammatic aphasia, and whether processing mechanisms differ per time frame.

The following paragraphs review additional relevant literature on agrammatic aphasic comprehension of time reference, and describe previous eye-tracking studies on processing of time reference in NBDs. Furthermore, some of the insights into IWAs' sentence comprehension provided by eye-tracking studies will be discussed.

5.1.1 Aphasiological time reference comprehension studies

Several studies investigated time reference in aphasia, but only a few of them included comprehension tasks. Nanousi, Masterson, Druks, & Atkinson (2006) reported results from grammaticality judgment tasks in Greek including a range of different verb forms: periphrastic future,[2] simple present, past continuous, simple past, and past perfect. IWAs made errors on all tenses. Faroqi-Shah and Dickey (2009) studied online grammaticality judgment of time reference (measuring reaction times) in agrammatic and healthy speakers of English. They did not distinguish between tense and time reference. To test future time reference, their materials included an auxiliary plus infinitive, e.g., *Next year/Last year, my sister will live in Boston.* For present time reference, they included a present tense auxiliary with an infinitive, for example, *These days/last month, my younger sister does not live in Boston*, and a lexical verb in simple present, e.g., *[...] lives [...]*. For past time reference they used a past tense auxiliary with an infinitive, e.g., *[...] did not live [...]*, or a lexical verb in simple past, e.g., *[...] lived [...]*. Response latencies for detecting violations by verbs with future time reference and past time reference were similar and both longer than for those by verbs with present time reference. Accuracy of IWAs did not differ between time frames and was lower than accuracy of NBDs.

Grammaticality judgment data are, however, not informative with respect to the point at which processing breaks down: errors can be due to incorrect processing of the temporal adjunct, the verb, or both. Sentence-picture matching tasks are more revealing in that respect. Jonkers and De Bruin (2009) showed that Dutch-speaking IWAs were more impaired in interpreting past tense inflection than present tense inflection. Bastiaanse and her colleagues (Bastiaanse et al., 2011) studied agrammatic comprehension of time reference using the sentence-picture matching task of the Test for Assessing Reference of Time (TART; Bastiaanse, Jonkers, & Thompson, 2008). This test includes the most frequently used verb forms for reference to the future, present, and past in three languages: English, Turkish and Chinese. The comprehension scores on future time reference were in between those on past and present; past was most difficult for agrammatic IWAs. Similar results were obtained for aphasic speakers of Catalan and Spanish (Martínez-Ferreiro & Bastiaanse,

[2]Nanousi et al. (2006) refer to the periphrastic future with the term 'simple future'.

2013). In a study involving Swahili-English agrammatic aphasic bilinguals, however, participants were selectively impaired in the past condition of the TART only (Abuom & Bastiaanse, 2013). These results suggest that for IWAs, the complexity of discourse-linking leads to errors in past time reference comprehension, whereas accuracy is higher for present. However, performance on future is prone to errors, too. In conclusion, past-time reference is impaired in agrammatic production and comprehension.

5.1.2 Eye-tracking studies manipulating time reference

Several studies demonstrated that eye movements are rapidly influenced by the interpretation of visual events, in particular the time reference deducted from them. In Altmann and Kamide (2007), participants heard sentences with past or future time reference such as *the man will drink...* or *the man has drunk...* while inspecting a panel containing a full and an empty glass, both potential sentence themes. At the onset of the verb phrase, proportions of looks at both objects were similar, but after the verb phrase the participants fixated more often on the full or empty glass in, respectively, the future and past condition. Altman and Kamide thus demonstrated that when healthy speakers of English interpret the time reference of a verb, they direct their gaze towards an object that is anticipated as the grammatical theme.

Also in real world events (with participants watching events acted out by the experimenter), it has been found that time reference guides anticipatory eye movements to the location of the grammatical theme; however, gaze patterns between sentences referring to the past versus the future differed (Knoeferle, Carminate, Abashidze & Essig, 2011). Participants listened to German sentences in either simple past with past time reference or simple present with future time reference as in (1) while inspecting a scene with two objects.

(1)	Der Versuchsleiter	[zuckert demnächst]/	[zuckerte kürzlich]	die Erdbeeren.
	The experimenter	[sugars soon]/	[sugared recently]	the strawberries.
	'The experimenter will soon sugar/recently sugared the strawberries.'			

During the disambiguating constituents (verb inflection and subsequent temporal adverb), participants preferred to gaze at the object involved in the recently seen event over the object not involved in an event yet. For sentences with future time reference, this recent-event preference was overcome only when hearing the direct object. The authors therewith replicated results of a similar experiment involving clip-art pictures (Knoeferle & Crocker, 2007, Experiment 3). They attribute the preference in looking towards the recently seen object as evidence that even in sentences containing a verb form and temporal adverbial referring to the future, listeners initially prefer to relate the action of a verb to a recently seen event.

The analysis included eye gazes towards two potential target objects for the verb's theme, for example, a plate with strawberries and a plate with a pancake for the verb to sugar. During the disambiguating constituents in both conditions, participants preferred to gaze at the object involved in the recently seen event over the object not involved in an event yet. For sentences with future time reference, this recent-event preference was overcome only upon hearing the direct object. The authors attribute the preference in looking towards the recently seen object as evidence that even in sentences containing a verb and temporal adverbial referring to the future, listeners initially prefer to relate the action of a verb to a recently seen event.

In conclusion, in neutral conditions, NBDs use the interpretation of time reference information to anticipate the object of a sentence. During the verb phrase, NBDs have a preference to inspect the location of a recently seen event, which is overcome when the sentence further unfolds.

5.1.3 Aphasiological eye-tracking studies

So far, no eye-tracking studies have investigated time reference processing in IWAs. However, eye-tracking has been used before in aphasia research and brought interesting insights into how IWAs comprehend sentences. Mack et al. (2013) showed that eye movements of IWAs indicate delayed lexical access during sentence comprehension compared to age-matched healthy adults. Previous studies found that when IWAs interpreted non-canonical sentence structures correctly, eye movement patterns were similar to those of NBDs (passives: Dickey & Thompson, 2009; object-verb-subject sentences: Hanne et al., 2011), although competition with incorrect referents of a clause was sometimes increased towards the end of the sentences (object *wh*-questions: Dickey et al., 2007; object relatives: Dickey & Thompson, 2009; pronominal reference: Choy & Thompson, 2010). In a study by Meyer et al. (2012),[3] eye movement data demonstrated that, compared to NBDs, IWAs are delayed in processing

[3] We refer to the results from IWAs' eye movements split by accuracy in comparison with NBDs.

active and passive sentences even when their offline response (in a sentence-picture matching task) was correct. Dickey and Thompson (2009) proposed that increased processing difficulty with some linguistic structures (such as object relatives in their study) leads to an extra delay in processing in IWAs, which is in line with self-paced listening data from Caplan et al. (2007).

Analysis of the eye-tracking data during comprehension of non-canonical sentences suggests that IWAs initially successfully process these sentences, but sometimes fail to continue to do so as the sentence unfolds: Differences occur close to or after sentence offset (Choy & Thompson, 2010; Dickey et al., 2007; Dickey & Thompson, 2009; Meyer et al., 2012).

5.1.4 Aims of the study

Our first aim was to find out whether NBDs and IWAs differ in correct online processing of future and past time reference inflection (that is, when offline responses on a sentence-picture matching task are correct). We expected NBDs and IWAs to show qualitatively similar eye movements for trials correctly understood by both groups, in line with previous studies demonstrating that IWAs have similar — albeit sometimes delayed — eye movement patterns as NBDs for correctly processed sentences (Choy & Thompson, 2010; Dickey et al., 2007; Dickey & Thompson, 2009; Hanne et al., 2011). However, as outlined above, more complex conditions, in our case past time reference, may lead to delays in processing by IWAs versus NBDs (viz. Caplan et al., 2007; Dickey & Thompson, 2009). Since past time reference is discourse-linked and hence more complex, and because it is impaired in aphasia according to the PADILIH, we expected delayed processing reflected in IWAs' eye movement patterns.

The second aim of the current study is to characterize processing patterns reflecting incorrect time reference interpretation. We predicted accuracy on the sentence-picture matching task to be at ceiling for NBDs. For IWAs, we expected equal or below-ceiling accuracy on the future than NBDs, and lower accuracy on the past than on the future, with longer reaction times for past than for future. When IWAs interpret time reference incorrectly, we expect gaze differences as compared to correct trials. Previous studies of non-canonical structures reported systematic differences between correct and erroneous responses (Choy & Thompson, 2010; Dickey et al., 2007; Dickey & Thompson, 2009; Hanne et al., 2011). It is difficult to say a priori what these differences will comprise and when they will arise, since this is the first study to investigate online time reference processing in aphasia within the visual world paradigm.

5.2 Methods

This experiment used the visual world paradigm with combined sentence-picture matching and eye-tracking in order to study the comprehension of past and future time reference inflection in German NBDs and IWAs. Furthermore, the offline comprehension subtest of the TART (Bastiaanse et al, 2008) was administered, which has been used in previous studies (e.g., Abuom & Bastiaanse, 2013; Bastiaanse et al., 2011; Martínez-Ferreiro & Bastiaanse, 2013) and has items for past, present and future.

5.2.1 Participants

There were two participant groups: 12 NBDs (C1-C12; 8 women, mean age 58.0, range 38-77)[4] with no history of neurological, psychiatric, or learning problems and 6 IWAs (B1-B6; 3 women, mean age 57.5, range 41-73). All participants were right handed and native speakers of German, except for B3, who was pre-morbidly left-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). They all reported normal or corrected to normal vision, and no hearing problems. Each participant signed an informed consent according to the Declaration of Helsinki under a procedure approved by the Ethics Committee of the University of Potsdam. The aphasia of the IWAs was due to a single left-hemisphere lesion, except for B3, who had a right-hemisphere lesion. The IWAs had non-fluent speech output that was effortful and telegraphic, with relative intact comprehension on the Aachen Aphasia Test (AAT; Huber, Poeck, Weniger, & Willmes, 1983). All IWAs' except for B2 were classified as Broca's aphasic using the AAT. B2 was initially diagnosed as Broca's aphasic, but had progressed to anomic aphasic. She exhibited substitutions of plural with single nouns, omissions of determiners and verb forms and sometimes substitutions of finite verb forms with an infinitive in her speech output, and she produced many incomplete utterances. In Appendix C.1, demographic data of the individual participants are provided.

[4]A 13th control participant was excluded because he reported problems with vision, due to the fact that he was not wearing his glasses during the experiment.

5.2.2 Materials and procedure for the TART

Participants were examined with the comprehension subtest of the German version of the TART (Bastiaanse et al., 2008) after the eye-tracking experiment. See Bastiaanse et al. (2011) for a full description of this test. This subtest is a sentence-picture matching task with 60 items: 20 transitive verbs in past, present and future condition. Every sentence was presented auditorily and consisted of three constituents: the subject (man or woman), the verb and the object. For example:

TART-Past	*der Mann hat den Zettel zerrissen* (lit. the man-NOM has the paper-ACC torn) 'the man tore paper'.
TART-Present	*der Mann zerreißt den Zettel* (lit. the man-NOM tears the paper-ACC) 'the man is tearing paper'.
TART-Future	*der Mann wird den Zettel zerreißen* (lit. the man-NOM will the paper-ACC tear) 'the man will tear the paper'.

5.2.3 Materials for the eye-tracking experiment

The stimuli of this study consisted of spoken sentences and pictures. Sentences were presented over a loudspeaker while participants inspected panels with two object pictures (for an example see Figure 5.1). The task was to select the picture that matched the sentence by key press. In a pretest, comprehension agreement for the pictures was tested with 30 university students. Only items with at most two errors were selected, resulting in an overall pretest accuracy of 98%.

Linguistic stimuli

Altogether, there were 60 experimental stimuli: 20 target items in two experimental conditions (Future and Past), and 20 fillers. Additionally, there were six practice items (two of each type). For each item, there was a short introduction sentence in which the subject and object were introduced (see Table 5.1).

The target sentences consisted of an imperative main clause and a subordinate clause, which conveyed the critical time reference information. The

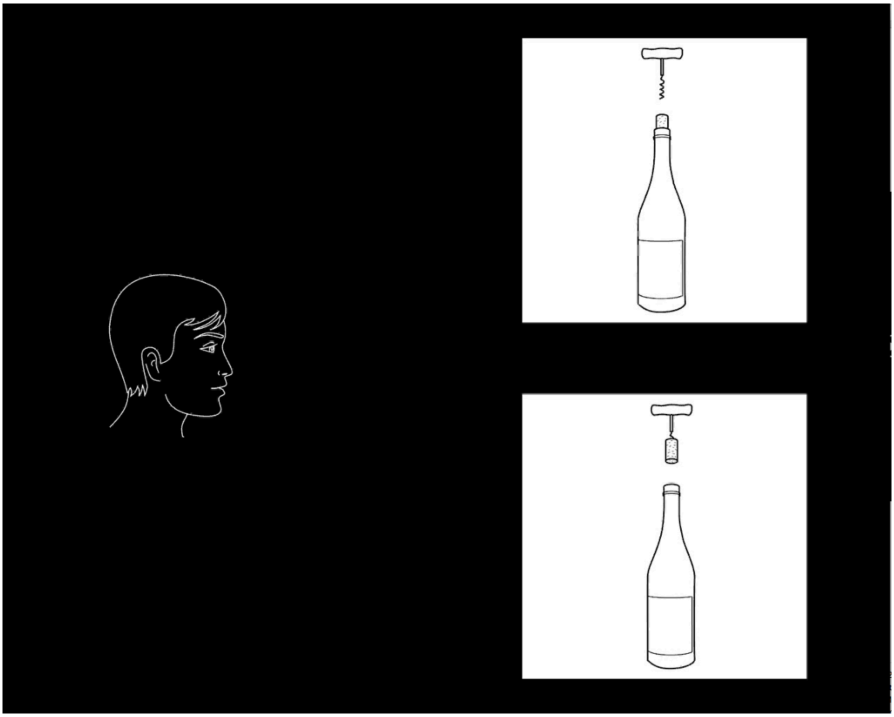

Figure 5.1: Sample visual display, inspired by Altmann and Kamide (2007). This visual display was shown throughout the whole item presentation given in Table 5.1, except the Show-ROI.

subordinate clauses contained transitive weak (regular) change-of-state verbs with an unstressed first syllable, starting with /*be*/-, /*de*/-, /*ent*/-, and /*ver*/-, as well as a set of verbs ending on -/*ieren*/. Each verb was used in both experimental conditions: Future and Past. For the Future condition, a combination of the auxiliary *wird*: 'will' and the infinitive of the lexical verb (periphrastic future). In German, future reference can also be obtained by the simple present, for example *sie fährt morgen*: 'she will drive tomorrow', which is more frequent (Thieroff, 1992). In order to have the inflection appearing at the same position in both conditions, we used subordinate verb-final clauses as target structures. For the Past condition, the periphrastic past (i.e., the present perfect) was used, generated by a combination of the third person auxiliary *hat*: 'has' and

Table 5.1: Auditory regions of interest (ROIs) with their onset times relative to picture and sentence onset, including 200 ms to account for saccade planning. Participants were able to preview the panel from the beginning during the 'SubjIntro' and 'ObjIntro' ROIs for 4000 ms. During the entire 'Show' ROI (500 ms), a smiley was shown centrally on the screen, which is why this ROI is not included in the analysis of eye movements to the target picture. Immediately after the smiley, the picture panel was shown again. The 'Silence' ROI lasted from the offset of the inflection ROI until the participant's response by key press.

Condition	**Auditory regions of interest (ROIs) with onset times plus 200 ms (to account for saccade planning)**								
	SubjIntro 201 ms	**ObjIntro 1601 ms**	**Show 4201 ms**	**WhichPic 4701 ms**	**Subject 6521 ms**	**Object 7481 ms**	**Stem [var.]**	**Inflection [var.]**	**Silence [var.]**
Non-past	Schauen Sie den Mann	und die zwei Flaschen an.	Zeigen Sie	auf welchem Bild	der Mann	eine Flasche	entkor-	-ken wird.	
	Look you the man-ACC	and the two bottles at.	Show you	in which picture	the man	a bottle	uncor-	-k will.	
	'Look at the man and the two bottles. Show in which picture the man will open a bottle.'								
Past	Schauen Sie den Mann	und die zwei Flaschen an.	Zeigen Sie	auf welchem Bild	der Mann	eine Flasche	entkor-	kt hat.	
	Look you the man-ACC	and the two bottles at.	Show you	in which picture	the man	a bottle	uncor-	-ked has.	
	'Look at the man and the two bottles. Show in which picture the man has opened a bottle.'								
Filler	Schauen Sie den Mann	und die zwei Flaschen an.	Zeigen Sie	das Bild mit dem Stern.					
	Look you the man-ACC	and the two bottles at.	Show you	the picture with the star.					
	'Look at the man and the two forms. Show the picture with the star.'								

Var = various per item for Stem and Inflection ROI, and additionally per subject for the Silence ROI. Stem ROI onset was 320 ms after the Object ROI offset.

the past participle. This is the usual form to refer to a past event in German. The past participle in German can take different forms, but in the current experiment all verbs used the suffix $-/t/$ on the stem of the lexical verb and no prefix $/ge/$- to mark the participle, for example *lackiert*: 'polished$_{\text{participle}}$'. In German subordinate clauses the verb complex is clause-final and the finite auxiliary follows the participle. Hence, in both conditions, the critical verb inflection appeared at the end of the lexical verb (-*t* in past, -*en* in future condition), before the sentence-final auxiliary. Examples for the introduction and target sentence for both conditions and the fillers are provided in Table 5.1. A complete list of the verbs used in the test is given in Appendix C.2.

The experimental stimuli were partitioned into auditory Regions of Interest (ROIs); see Table 5.1 for examples and their onset times, which was 1 ms after offset of the previous ROI. The introduction sentence consisted of the SubjIntro ROI, in which the subject was introduced, for example: 'Look at the man', and the ObjIntro ROI, in which the object was introduced, for example: 'and the two bottles'. In the Show and WhichPic ROI participants heard the imperative form of to 'show' and the clause 'in which picture', respectively. The Subject ROI consisted of the subject of the subordinate clause (either 'the man' or 'the woman'). The Object ROI contained the subordinate clause's object noun with a determiner, for example: 'the bottle'. The Stem ROI comprised the lexical verb until one phoneme before the onset of the inflection, for example: 'entkor-'. The Inflection ROI encompassed the inflection of the lexical verb and the auxiliary, for example: '-kt hat' for Past or '-ken wird' for Future, and the Silence ROI consisted of the period of silence until the participant responded by key press (see Apparatus and eye-tracking procedure).

Filler sentences had a similar structure until she Show ROI, followed by *das Bild mit*: 'the picture with' and a noun phrase, in some cases with an adjective. Object pictures were semantically related to each other: a tulip served for example as a distractor for the target 'the rose'. Thus, responding to the fillers did not request interpretation of time reference information.

The sentences were recorded monaurally in a sound proof studio from a native, female speaker of German. One recording was used for each experimental lexical verb pair, cross-spliced up to and including the direct object of the experimental sentence. For half of the materials, the verb with past time reference was spliced onto the future sentence, and for half of the materials the verb with future time reference was spliced onto the past sentence. This way, differences in intonation, length, pitch etcetera between the experimental conditions until the critical verb phrase were avoided. In all experimental sentences, timing of presentation of the sentence constituents was manipulated to be similar until the onset of the target object by lengthening or shortening the silence at the end of each ROI.[5] Since lexical verb and object differed per item pair, timing of sentence constituents diverged from the sentence onset, onwards. Between the offset of the object and the onset of the verb phrase, 320 ms of silence appeared. Adobe Soundbooth CS4 (Adobe Systems Incorporated) was used to align the auditory sentence constituents across items and to remove smacks and hisses.

The period between verb onset until the last stem consonant did not differ significantly across conditions (future stem: 411 ms, past stem 423 ms; $t(39) = 1.46$, $p > .05$). The final phoneme of the stem was not included in the Stem ROI, but in the Inflection ROI, to minimize coarticulation effects of the subsequent inflection on the verb stem in this ROI. The Stem ROI duration was matched across conditions by shortening the longest Stem ROI per item pair (in analysis, not in acoustic signal). The mean duration of the final stem phoneme plus the inflection differed between conditions: Future 597 ms (SD = 40 ms) and Past 474 ms (SD = 39 ms; $t(19) = 11.63$, $p = .001$). This was because the lexical verb was not manipulated acoustically. Therefore, the Inflection ROI was lengthened by including silence (mean duration 124 ms) after the auxiliary in the Past condition, equaling its duration to that of the Future condition.

Visual stimuli

Pairs of black-and-white line drawings were developed in Adobe Illustrator CS4 (Adobe Systems Incorporated) depicting the object of each subordinate clause in Future and Past condition, respectively, or two semantically related objects for the filler items. For the Future condition, the object was depicted in the state before the event (e.g., an unopened wine bottle for ‘to uncork’), whereas for the past condition the object was depicted in the state after the event (e.g., an open wine bottle for ‘to uncork’). The two object pictures were placed one above the other. In addition to the two pictures of the object, the subject of the sentence (either a man or a woman) was depicted to the left hand side of the object pictures. Figure 5.1 shows a sample of the visual display for the

[5]The manipulation of the silence at ROI (i.e. constituent) boundaries was kept to a minimum, because the lexical material until object onset was the same in all experimental sentences. No participant reported that items sounded unnatural.

experimental sentences of Table 5.1.

5.2.4 Apparatus and eye-tracking procedure

A table-mounted remote Tobii T120 (Tobii Technology AB, Stockholm, Sweden) eye-tracking system was used to track at a sampling rate of 60 Hz in a double computer solution (binocular tracking, accuracy: 0.5 degrees, head-move-tolerance: 30 x 22 x 30 cm). Picture panels were presented on the screen of the eye-tracker (screen size: 17 inch, resolution: 1280 x 1024 pixels) in an AVI-file with CINEPAK codec created in Adobe Flash CS4 (Adobe Systems Incorporated) using Tobii Studio software 1.7.2 (Tobii Technology AB), which was also used for data collection.

The practice trials were administered on paper by the experimenter before the eye-tracking experiment and repeated if the participant made an error. Then, the participants were seated in a comfortable chair approximately 60 cm in front of the monitor and performed the sentence-picture matching task. They were asked to press the upper arrow key with the index finger or the lower arrow key with the thumb of their non-dominant hand to indicate whether the upper or lower picture, respectively, matched the sentence. Maximum response time was set at 10 seconds after sentence offset. The picture size was 410 x 410 pixels for the target and foil object picture and 190 x 240 pixels for the picture of the subject (man or woman). After a 9-point calibration procedure, during which red dots were displayed on a black screen, the online practice phase started. Calibration was repeated before the beginning of the test phase and after a 5-10 minute break halfway during the experiment. Total testing time with the eye tracker was between 15 minutes and 30 minutes. Eye movements, accuracy and response time (from the onset of the object NP of the subordinate clause) were measured.

Two pseudo-randomized presentation lists were constructed in which no more than two adjacent items were of the same condition, and in which the initial item after calibration and every third one following was a filler item. Each verb (with corresponding pictures) appeared twice in the experiment; therefore, the first and second occurrences of a verb were spread evenly over conditions. Between two occurrences of the same verb, an average number of 24 trials appeared (range 9-41). Fillers appeared at the same trial position across lists, but conditions of a verb were alternated to create two counter-balanced lists. Target picture placement (upper versus lower) was balanced (10:10 across conditions including fillers) and pseudo-randomized so that maximally three consecutive targets were located at the same position. For filler sentences, half of the object pictures were targeted twice to discourage developing a strategy of clicking on the not-yet-targeted picture.

The picture preview was shown for 4000 ms during which the introduction sentence was played conveying information on the three pictures in the panel, including a 1000 ms break before the critical sentence starts. The experimental sentence started with the Show ROI, during which the presentation of the visual display was interrupted and instead a smiley appeared for 500 ms in the middle of the screen to center the participant's gaze before the onset of the critical sentence constituents. The critical object started at 7280 ms in all the experimental sentences. Timing of the ROIs is indicated in Table 5.1.

5.2.5 Data analysis

To analyze the data, linear mixed-effects regression analyses were carried out using the *lmer* function of the *lme4* package (Bates, Maechler, & Bolker, 2013) in R (R Core Team, 2013). Eye movement plots were assembled using the *ggplot2* function 0.9.3.1 (Wickham & Chang, 2013). In the regression models, we included random effect predictors for participants and items, and the most significant random slopes that still yielded a converging model. Stepwise model comparison was based on the Akaike Information Criterion (AIC): predictors were deleted if that did not increase the AIC and if that resulted in a converging model. Absolute t- and z-scores greater than 1.96 were considered significant.

For the analysis of the TART data of IWAs,[6] we used logit-linked accuracy (1 = correct, 0 = incorrect). We compared condition predictor levels (TART-past, TART-present, and TART-future) to each other using post-hoc Tukey's contrasts. Model comparisons tested the significance of by-participant and by-item random slopes for predictors Condition and Trial number, as well as fixed effects and an interaction between those predictors.

For the eye-tracking experiment, behavioral and eye movement analyses included the predictor Participant group, for which we coded NBDs as baseline category (0) to which IWAs (1) were compared. The coding contrast for the Condition predictor was 0 for future and 1 for past. A Baseline picture pref-

[6] NBDs scored at ceiling on the TART and these data were further ignored.

erence predictor[7] was calculated for each participant and trial based on the proportion of looks to the past versus the future target picture in ObjIntro ROI, in which participants were asked to inspect both object pictures. This was done to account for any a priori minor differences in visual attractiveness of the stimuli. Values ranged between 0 (no past picture preference) and 1 (only looks to the past picture) with mean 0.52, which means that averaged over trials, the participants inspected both pictures almost equally long during the ObjIntro. However, for a given trial participants might have preferred the past picture (this will be discussed below).

For the behavioral analyses of the eye-tracking data we used (a) logit-linked accuracy (1 = correct, 0 = incorrect) and (b) log-transformed correct response times from the object onset onwards. Model comparisons tested the significance of by-participant and by-item random slopes for Participant group (only by-item), Condition, Trial number (i.e., the numerical position of the trial within the presentation list), Picture repetition (i.e., first and second appearance), Baseline picture preference, and Age, as well as fixed effects of those factors.

For analyses of eye-movements, saccade planning was accounted for by shifting the duration of all ROIs 200 ms forward, which has been shown to be sufficient for both NBDs and IWAs (Altman & Kamide, 2004; Dickey, Choy, & Thompson, 2007). IWAs' data were partitioned into correct and incorrect responses. The dependent variable of the eye movement models was the proportion of looks to the target versus the foil object picture with random effect factors for participants and items. The full model contained the fixed effects of Participant group, Condition, ROI, Trial number, Picture repetition, and Baseline picture preference. For the ROI predictor, successive backwards difference coding was used, comparing the fixation proportion of each ROI to that of the preceding one, from the Subject ROI (versus the WhichPic ROI) onwards.

The distribution of the statistical models' residuals for the eye-tracking data was visually inspected using quantile-quantile plots for close adherence to the diagonal line. In addition, the standardized residuals were analyzed. The assumption of normality was met, meaning that 5% or less of the standardized residuals of the model had a z-score of 1.96 or greater, a maximum of 1% of them a z-score of 2.58 or greater, and none of them a z-score of 3.29 or greater.

[7] The results reported are obtained with an uncentered predictor, because centering lead to convergence problems for some models. However, leaving the predictor uncentered was justified because the zero point was meaningful and for the converging models the overall results are not different from when a centered predictor was used.

5.3 Results

The mean accuracies and response times are shown in Figure 5.2 and plots of the proportion of eye movements to the correct versus foil object picture Figure 5.3. Individual accuracies and response times per participant can be found in Appendix C.3.

5.3.1 TART

The NBDs scored at ceiling in all three conditions of the TART (past, present, future) and we did not analyze these data any further. The model that best described the IWAs' data contained random effects for items and participants, with a random slope for condition per participant. Furthermore, it contained a fixed effect of Trial number, the slope of which was not significant ($\beta = 0.01$, $SE = 0.01$, $z = 1.21$), and Condition. Tukey's contrast showed that the TART-past and TART-future both differed significantly from the TART-present, but not from one another (TART-past versus TART-present: $\beta = 2.87$, $SE = 0.86$, $z = 3.35$; TART-future versus TART-present: $\beta = 2.63$, $SE = 0.75$, $z = 3.53$; TART-past versus TART-future: $\beta = 0.24$, $SE = 0.36$, $z = 0.66$).

5.3.2 Accuracy and RTs online sentence-picture matching

The best-fitting random effect structure for accuracy contained the random effects of Participant and Item without random slopes. Model AIC comparisons revealed a two-way interaction between the fixed factors of Participant group and Condition. Overall, IWAs responded less accurately than NBDs ($\beta = 3.09$, $SE = 0.63$, $z = 4.92$). There was no overall difference between the Future and Past condition ($\beta = 0.98$, $SE = 0.68$, $z = 1.43$), however, the interaction indicated that the difference between conditions was significantly larger for IWAs than for NBDs, meaning that IWAs were less accurate on Future than on Past ($\beta = 2.06$, $SE = 0.87$, $z = 2.36$).

The best-fitting random effect structure for log-transformed response times for correct responses contained random slopes for Condition by Participant, and for Participant group interacting with Picture repetition by Item. Model comparisons revealed main effects of Participant group and Condition and a main effect of Picture repetition. Overall, IWAs responded slower than NBDs ($\beta = 0.31$, $SE = 0.05$, $t = 6.21$). Responses to the Past condition were overall faster than to Future condition (β = 0.12, *SE* = 0.02, *t* = 5.04). Participants of both groups responded faster when they saw a picture for the second versus the first time (β = 0.03, *SE* = 0.01, *t* = 2.86).

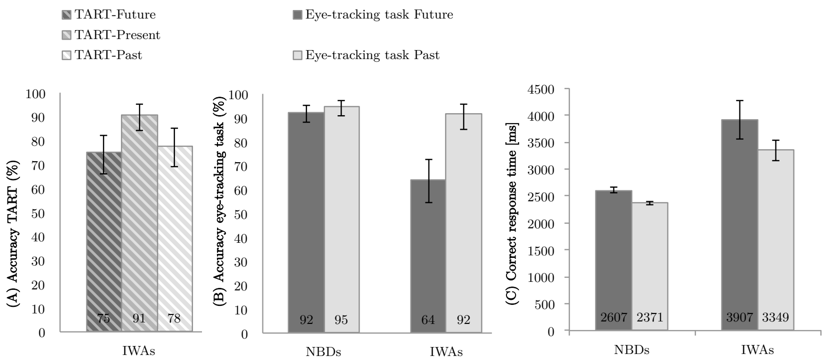

Figure 5.2: Overview of the accuracy (A) of IWAs on the TART, and the accuracy (B) and correct response times (C) of key presses in the sentence-picture matching task of the eye-tracking experiment. The response time is calculated from the object onset onwards.

5.3.3 Eye movements

First, correct data of NBDs versus IWAs were analyzed. The proportion of looks to the target versus the foil object picture per ROI was the dependent variable. The best-fitting random effect structure for correct answers contained random slopes for the Baseline picture preference interacting with Condition by Participant, and for Baseline picture preference and Picture repetition by Item. Model comparison revealed a three-way interaction between the fixed factors of Participant group, ROI, and Condition. There was an overall (i.e., over ROIs and participants) higher proportion of looks to the target picture in the Past than in the Future condition (β = 0.12, *SE* = 0.02, t = 6.14). Across both participant groups, the proportion of looks changed significantly from the previous ROI in the Inflection ROI (β = 0.14, *SE* = 0.03, *t* = 4.16) and in the Silence ROI (β = 0.24, *SE* = 0.03, *t* = 7.06). During the Silence ROI, the overall increase (i.e., for both groups) in proportion of looks to the target picture compared to the previous ROI was smaller for the Past condition than for the Future condition (β = 0.17, *SE* = 0.05, *t* = 3.28). To interpret the three-

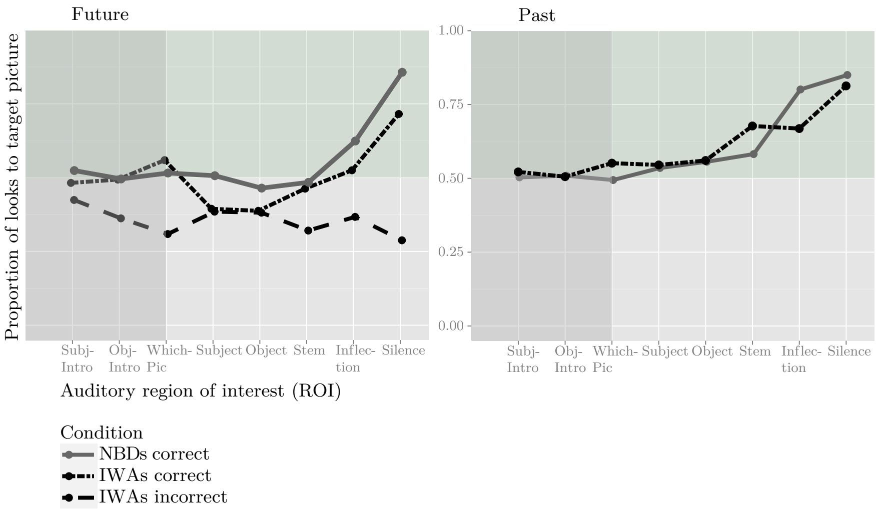

Figure 5.3: Eye movement plots. The statistical analysis included ROIs from WhichPic onwards (non-shaded). Past incorrect is not shown for IWAs, because there were not enough data for analysis.

way interaction in the model, the data were broken down along the variable Condition, while keeping the remaining model the same and with both models including the variables of Participant group and ROI.

Future condition: For the correct responses to the Future condition, model comparison showed main effects of Participant group and ROI, but no interaction between them. Overall, the IWAs looked less towards the future target picture than NBDs ($\beta = 0.07$, $SE = 0.02$, $t = 3.13$). For both groups, the proportion of looks towards the target picture increased with respect to the previous ROI during the Inflection ROI ($\beta = 0.11$, $SE = 0.03$, $t = 4.13$) and during the Silence ROI ($\beta = 0.24$, $SE = 0.03$, $t = 8.53$).

Past condition: The analysis of correct responses to the Past condition revealed an interaction between Participant group and ROI ($\chi^2\,(5) = 20.48$, $p < .01$). The proportion of looks towards the target picture increased significantly with respect to the previous ROI during the Inflection ROI ($\beta = 0.22$, $SE = 0.03$, $t = 6.95$) and Silence ROI ($\beta = 0.07$, $SE = 0.04$, $t = 1.95$). IWAs showed a less steep increase in looks towards the past target picture compared to NBDs upon hearing the Inflection ($\beta = 0.23$, $SE = 0.06$, $t = 4.11$) as revealed by the interaction.

Correct and incorrect responses: In a separate analysis on IWAs' eye movement proportions, both correct and incorrect responses to the Future condition were included as factor Accuracy – this analysis was not performed for the Past condition, because of their high accuracy and resulting lack of sufficient data points. The random effect structure was the same as for the participant group analysis above, excluding condition as a random slope. The best fitting converging model contained a two-way interaction between the fixed factors of ROI and Accuracy. The proportion of looks towards the target picture was overall higher for correct responses than for incorrect responses ($\beta = 0.14$, $SE = 0.03$, $t = 4.40$). In the Silence ROI compared to the previous ROI, there was a marginally significant increase in this difference in proportions ($\beta = 0.18$, $SE = 0.10$, $t = 1.84$).[8]

5.3.4 Summary of the results

The outcomes of the TART showed that the IWAs are impaired in comprehension of past and future time reference inflection, while comprehension of present time reference inflection is relatively intact. As expected, NBDs showed no comprehension problems on this test. In the behavioral data of the eye-tracking experiment, the only below-ceiling accuracy was performed by IWAs on the Future condition. Response times of NBDs and IWAs were longer for the Future than for the Past condition. The eye movement analysis showed that NBDs and IWAs processed future time reference similarly, but IWAs were relatively delayed on processing past time reference inflection. In both groups, there was an overall preference to look towards the target past picture. Incorrect parsing of the Future time reference condition was reflected in a great number of looks to the non-target past picture and finally resulted in incorrect key presses.

[8] In the Subject ROI versus the previous ROI, correct responses had a marginally significant smaller increase in looks towards the target picture as compared to incorrect responses ($\beta = 0.19$, $SE = 0.10$, $t = 1.90$). Since the Smiley ROI — during which a smiley instead of the picture panel was shown — precedes the subject, it is unlikely that this early difference is meaningful and it will be further ignored.

5.4 Discussion

With the current study we aimed to reveal (1) whether NBDs and IWAs differ in correctly processing future and past time reference inflection, and (2) what processing patterns underlie incorrect time reference interpretation in IWAs. According to the PADILIH, for the interpretation of past time reference, discourse-linking is needed — but not for future time reference interpretation. Discourse-linking requires additional processing resources at the level of discourse syntax, and this is what lacks in IWAs (Avrutin, 2000, 2006). We will discuss both aims below and will show that our results are in line with the tenets of the PADILIH. We will then discuss the TART data.

5.4.1 Correctly interpreted time reference in NBDs vs. IWAs

Our first aim was to characterize differences between NBDs and IWAs in correctly processing future and past time reference inflection. Eye movement patterns in the Future and the Past condition differed overall in both groups, which was expected on the basis the behavioral responses in this experiment (longer RTs and, for IWAs, lower accuracy in the Future than in the Past condition). However, interesting with respect to the PADILIH is that the NBDs and IWAs had similar eye movements when sentences were processed correctly in the future time reference condition, yet when they processed past time reference inflection, the IWAs showed a delay with respect to NBDs, reflected in an increase of their looks to the target picture one ROI later (Silence ROI). This is in line with our predictions based on previous eye-tracking studies (Dickey et al., 2007; Dickey & Thompson, 2009; Choy and Thompson, 2010; Hanne et al., 2011; Dickey et al., 2007) and the notion that IWAs generally require more time to process more complex materials (Caplan et al., 2007; Dickey & Thompson, 2009). As a result of a processing deficit (Caplan et al., 2007), IWAs show a delay in interpreting the inflection for past, because access to discourse structure is impaired in IWAs (Avrutin, 2006). This delay in processing past time reference inflection is paradoxical when the RTs of the picture selection task are taken into account: In the remainder of this section we will discuss how this paradox can be resolved.

In correct trials, there was a longer response time to Future than to Past stimuli in both participant groups: a difference of 235 ms for NBDs and of 558 ms for IWAs — without an interaction between Participant group and Condition. Part of this difference can be ascribed to the fact that the future verb form typically has one syllable more than the past verb form. The future verb forms (stem and inflection) were 111 ms longer than the past verb forms.[9] This length difference is a limitation of our choice not to manipulate the phonetic signals in order to keep the natural characteristics of the suffix in the future condition. Another source of this increased response time may be the fact that for past reference, we used the most frequent spoken verb form, while for future reference we used the periphrastic future, although in German the simple present is most frequently used to refer to the future (Thieroff, 1992). However, as frequency of use of grammatical constructions does not to play a major role in performance of IWAs (see Bos & Bastiaanse, 2014; Martínez-Ferreiro & Bastiaanse, 2013; Bastiaanse, Bouma, & Post, 2009; Faroqi-Shah & Thompson, 2004), we assume this is not the correct explanation.

Instead, we argue that the increased duration in response times in the future condition should be attributed to the pre-existing advantage to look at the past over the future picture. This is visible in Figure 5.3 as the difference between the lines for future and past in both participant groups.[10] This preference has to be overcome for future reference interpretation, thus leading to increased response times in both participant groups.

The past picture preference which we found in our study has not been reported in earlier studies. In their study with NBDs, Altmann and Kamide (2007) used few change-of-state verbs in their materials and, moreover, they showed pictures of two different objects, for example, a wine glass and a beer glass, so that no prototypical past picture was included. However, Knoeferle et al. (2011) found that locations of recently seen events attract more eye gazes during verb processing than potential target locations of future events. This finding is similar to the past-picture preference observed in our study. Nevertheless, some important differences in experimental design between our study and Knoeferle et al.'s suggest different causes of the past picture preference. Knoeferle et al. used real-world events, while in the current experiment no events were depicted — only the state of the object before and after the event

[9]Note that for the eye movement analysis the ROI durations were adjusted per condition, so that this difference is only of importance to the response time analysis.

[10]It is important to note that the backwards difference coding we applied for the ROI predictor in the statistical analyses limits the influence of pre-existing picture preferences in the analysis and interpretation of the eye movement data. However, Picture repetition was accounted for in the by-item random slopes of the model.

was shown. In addition, in Knoeferle et al., no particular task was given and the verb occurred before the sentential object, so that looks to the event locations were anticipatory and reflecting incremental sentence comprehension. In our experiment, however, participants were asked to select the appropriate object picture, which was mentioned in the target sentence before hearing the verb form. Earlier looks towards the object pictures may, therefore, reflect a hypothesis driven guess on which lexical verb was going to be used. Crucially, a past picture contains more relevant information, because it shows the result of the event of a change-of-state verb and this makes past pictures more salient as compared to pictures showing future events. See for example Figure 5.4, with the pictures used for the verb *verbeulen*: 'to bump'. Thus, in contrast to in Knoeferle et al., where the recent-event preference was a direct manifestation of anticipatory eye movements during incremental language processing, the past picture preference in our study may have been caused by features inherent to the materials used and could be a result of attraction to more salient visual information.

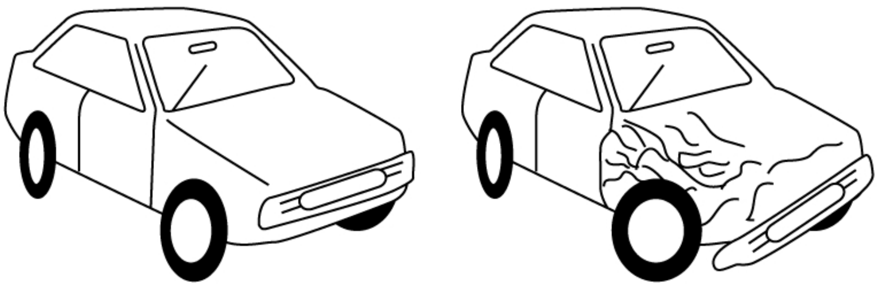

Figure 5.4: Pictures of a car used for the items with *verbeulen*: 'to bump'. The left one served as target for the Future condition, the right one for the Past condition.

To summarize, NBDs and IWAs were slower to press the correct key in the Future than in the Past condition, which can be ascribed to a past picture preference. Crucially however, IWAs were delayed with respect to the NBDs in interpreting past time reference inflection reflected in a delay directing their gaze to the target picture. Contrastingly, directly upon hearing future time reference inflection both groups interpreted it, reflected in increased gazes to the target picture.

5.4.2 Incorrect time reference processing

The second aim was to characterize underlying mechanisms of time reference comprehension failure of IWAs. The TART showed that the German IWAs were similarly impaired in comprehension of future and past time reference compared to present time reference. Surprisingly, comprehension scores and response times in the eye-tracking experiment suggested that past time reference is easier than future time reference for these IWAs. However, the preference to look at the past picture before the critical inflection has been heard and the tendency not to switch to the other picture must have played a role. While NBDs successfully overcame this looking preference, IWAs were struggling in doing so. For sentences in the past condition, IWAs already looked at the target (past) picture more often before the inflection was perceived, so that no preference had to be overcome and, hence, they were less prone to make errors compared to the future condition. This idea is in line with recent suggestions on cognitive processing in aphasia ascribing an enhanced role to task-demands and task-effects on language comprehension performance in IWAs (Caplan, Michaud, & Hufford, 2013).

The accompanying eye movement patterns reveal that for incorrect responses in the future condition, IWAs fixated overall more on the non-target (i.e., the past) picture than in the correct condition. During the silence between sentence offset and response, the gaze patterns for correct and incorrect responses show a tendency to diverge. The data in Figure 5.2 suggest that during correct processing, IWAs further increase their looks to the target picture, while during incorrect processing, they increase their looks to the non-target past picture. In other words, when IWAs process future time reference incorrectly, they are looking to the incorrect (i.e., past) picture early on in the sentence, they fail to switch their attention (reflected in their gaze) to the correct picture, and finally they select the wrong picture.

A question that remains is why the IWAs do not show a similar past picture advantage in the TART. Some differences between the procedure and materials of the TART and the eye-tracking experiment are relevant with regards to this question. First, there was time pressure during the eye-tracking task, but not during the TART. Furthermore, with respect to the sentences used, the position and order of the verb phrases is different, because the TART uses main clauses with the finite verb (simple present lexical verb or auxiliary) appearing before the object, which precedes the infinitive/participle. In contrast, the eye-tracking experiment used embedded sentences with a sentence-final complex consisting of an auxiliary and lexical verb. Putting the verb inflection relevant for the interpretation at the end of the sentences and adding time pressure may have increased the working memory load which is limited in IWAs (Caplan et al., 2007).

5.4.3 Conclusion

In the eye-tracking experiment, sentences with verb forms referring to the future were more difficult than sentences with verb forms referring to the past for both participant groups, as demonstrated by accuracy and response time. The important finding of our study is that IWAs interpret future time reference similarly to NBDs, as demonstrated by eye movement patterns during and after the verb phrase. However, IWAs' interpretation of past time reference inflection is delayed compared to NBDs, as revealed by eye movement patterns during and after the verb phrase. The latter finding supports the PADILIH that postulates that processing discourse syntax requires additional resources and is, therefore, problematic for people with aphasia. When IWAs make errors on sentences with future time reference, eye movement patterns suggest that these errors arise because IWAs fail to overcome the past-picture preference and to switch their attention to the future target picture at the end of the sentence. Since in NBDs as well as IWAs the past-picture preference emerged early in the sentence, before the time reference inflection, it does not relate to processing of time reference inflection.

Further aphasiological research may clarify how online processing of present and past time reference differs. Furthermore, generalizability of the current results to other languages and verbs should be investigated, because the current study employed change-of-state verbs without the typical prefix *ge-* on the participle.